# THE SUN AND THE WEATHER: NEW LIGHT ON THEIR RELATION

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The psychology of great advances in science is most fascinating. As long ago as 1651, as we learn from Professor Helland-Hansen and Dr. Nansen in a recent elaborate monograph,[1] Father Riccioli, a Jesuit priest, announced that when sunspots are numerous the temperature of the earth's surface falls, whereas when spots are few the temperature rises. In 1801 the great astronomer Herschel confirmed this conclusion. Then in 1826 the Bavarian astronomer Gruithuisen showed that when sunspots are numerous the storminess of the earth increases. Thus a century ago the two main facts as to the relation between solar changes and terrestrial weather were already known.

## The Greatest Meteorological Problem of the Day

### The Anomaly

For a hundred years, however, there has raged a great controversy over this question—a controversy of ever increasing intensity. At last the work of many students, and especially the final tabulations of Köppen, published in 1914, have placed one phase of the matter beyond the possibility of question: the temperature of the earth as a whole falls when sunspots increase and rises when they decrease. At the same time the measurements of the sun's radiation made by Abbot and others are rendering it more and more clear that the sun emits more heat when sunspots are numerous than when they are few. Thus the anomaly of a warmer sun and a cooler earth appears now to be well established. Nevertheless, so far as the writer is aware, no weather bureau in any of the great countries of the world has officially admitted the truth of this relationship.

### Relation between Solar and Terrestrial Atmospheres

The controversy over the reality of a connection between the activities of the sun's atmosphere and that of the earth being almost ended, a new question has arisen. What is the nature of this connection? The conservative school holds that the connection must be purely thermal. An unusual supply of heat from the sun must warm the surface of land and sea. The warming of the sea must be of especial importance. This is

[1] Björn Helland-Hansen and Fridtjof Nansen: Temperaturschwankungen des Nordatlantischen Ozeans und in der Atmosphäre: Einleitende Studien über die Ursachen der klimatologischen Schwankungen, *Kristiania Videnskapsselskapets Skrifter: Mat.-Naturv. Klasse, 1916*, Art. 9 (pp. 1-341). Christiania, 1917. The present paper is based on this important work on the relation between solar and terrestrial changes. See also Nansen's abstract in *Journ. Washington (D. C.) Acad. of Sci.*, Vol. 8, 1918, pp. 135-138.

partly because evaporation, cloudiness, and rainfall must thereby be increased, and partly because the heat received by the water, especially in equatorial regions, is transferred to other regions by means of ocean currents. As to the anomaly of a warm sun and a cool earth the supporters of this school offer various explanations. Some hold that increased evaporation causes increased cloudiness and thus shuts out the sun's heat, thereby lowering the surface temperature. This seems much like reasoning in a circle. Hence others believe that the oceanic circulation is so altered that more cold water wells up from beneath and thus the temperature of the surface is lowered. Still others, following Humphreys, believe that at sunspot minima, when the sun emits less than the usual amount of heat, the proportion of ultra-violet rays in the sunlight increases. This is supposed to be due to the relative clearness of the sun's atmosphere, which at such times is comparatively free from prominences or protuberances formed by clouds of gases at high altitudes. The ultra-violet light is supposed to increase the formation of ozone in the upper layers of the atmosphere. Ozone permits waves of short length, such as those of light, to pass through it easily. It hinders the waves of greater length, that is the heat waves which radiate from the earth into space. Thus the ozone is thought to act as a blanket and keep the earth warm at times of few sunspots, while at times of many spots the heat waves are allowed to escape.

## Theory of the Radical School

The radical school rejects the idea that changes in the temperature of the earth's surface are the primary cause of the climatic variations which seem to be associated with changes in solar activity. They believe that the primary cause is found in the atmospheric circulation. The group of students who hold this belief in one form or another includes the two Lockyers, Bigelow, Veeder, Kullmer, and others; it is now re-enforced by the Norwegian authorities, Professor Helland-Hansen and Dr. Nansen, the Arctic explorer. The members of this radical group hold that when the sun is active it somehow causes changes in the upper atmosphere. Thus the distribution of atmospheric pressure is disturbed, the strength of the winds is increased, and especially the location, area, and relative intensity of centers of high and low pressure are altered. This causes such changes in the strength and direction of the winds that corresponding changes in temperature occur, and the effect of increased solar heat may actually be reversed. Veeder, basing his opinion upon a study of centers of high pressure, believed that when the sun is active great masses of the upper air are transferred bodily to those centers. This air is supposed to descend and cool the lower atmosphere, while at the same time its movements disturb the atmospheric equilibrium and thus give rise to more abundant and stronger storms. The writer, basing his opinion upon a study of centers of low pressure, has come to a similar conclusion. He believes that at times

of solar activity the well-attested increase in the cyclonic activity of ordinary storms, thunder storms, tropical hurricanes, and the like carries great masses of relatively warm air to high levels. There it grows cool. Thus it radiates into space the extra heat received from the sun at such times. It even carries this radiation to such a point that the earth's surface is actually cooler at times of abundant solar radiation than at times when less heat is received and when the earth's atmosphere is less active. This belief, it will be seen, is essentially the same as Veeder's, the two being opposite sides of the same shield.

The radical group of meteorological students are often regarded by their colleagues as visionary. There is some ground for this opinion. The conservative group appeals to a motive force, or type of energy, whose efficacy is undoubted. The effect of heat can be seen by everyone every day in the year. Therefore the group of students who assert that thermal conditions are sufficient to explain all meteorological phenomena feel that they are on safe ground. The radical group is obliged to confess that in this respect it is at a distinct disadvantage. It is forced to appeal to some other motive energy whose mode of action is not so clear as that of heat. The sun emits light, heat, and the types of energy known as electrical, magnetic, and radioactive. Among these, aside from heat, the electromagnetic group is the most probable source of disturbances in the earth's atmosphere. Therefore the radical meteorologists generally believe that electro-magnetic energy must have something to do with the relation between the solar and terrestrial atmospheres. Nevertheless they do not yet know quite how their supposed force can produce the observed effects. They feel, however, that this difficulty is less than the difficulty of holding to a purely thermal hypothesis in the face not only of the great anomaly of a warm sun and a cool earth, but of many minor anomalies.

## Radical and Conservative Positions

One important point needs emphasis. The conservative school does not regard temperature as the solution of the whole question, nor does the radical school regard atmospheric circulation as the whole solution. The conservative meteorologists merely say that the chain of events *begins with temperature*. An unusual degree of heat on any part of the earth's surface causes changes in atmospheric pressure and also in the temperature gradients between different parts of the ocean. This leads to winds, ocean currents, storms, and precipitation. These in turn lead to further changes of temperature. Thus new conditions of atmospheric pressure and of oceanic gradients are established, and the wheel comes round full circle.

The radical meteorologists believe in exactly the same circle of events. They do not question the importance of changes of temperature. No sane man who knows how the seasons cause the most extreme changes in every kind of climatic conditions can possibly do so. They admit freely that

variations in solar radiation due to the differing angle of the noonday sun are the most important of all climatic phenomena. They also admit with equal readiness that any change in the amount of heat received from the sun is bound to have the effects claimed by the conservative school. The point where they part from their fellows is merely this: The temperature changes in the sun appear to them to be accompanied by changes of other sorts. These other changes apparently act more rapidly and violently than the thermal changes. They may mask or even for a time reverse the thermal effects, but this does not mean that they are any more important. The variations in the sun's heat may be compared to the currents caused by the ebb and flow of the tide; the other variations, whatever their origin, may be compared to the waves and currents raised by the wind. Both sets of activities must be understood in order that a ship may safely reach harbor. The sun's non-thermal changes apparently act directly upon the earth's atmospheric activity. Hence the radical school holds that the more noticeable effects of solar variations *begin with the circulation of the air* and thus produce changes in temperature, ocean currents, rainfall, and the like.

## Means of Settling the Controversy

In order to settle the controversy between the conservative and the radical meteorologists four lines of investigation suggest themselves. First, we must study the earth's weather anomalies, that is the incidental variations such as the cold winter of 1917-18. In this way we must determine whether unusual climatic conditions begin with changes in the temperature of the earth's surface or with changes in the distribution of atmospheric pressure. The monograph by Professor Helland-Hansen and Dr. Nansen here under consideration is a study of this problem.

Second, we must carry on a more intensive study of the sun itself in order to determine how far the connection between its changes and those of the earth's atmosphere can be attributed to thermal conditions and how far it must be attributed to other causes. Such a study has recently been completed by the writer and will shortly be published in the *Monthly Weather Review.*

Third, if there seems to be ground for the radical opinion as to the importance of non-thermal solar variations, we must carefully review the sun's activities to see whether there is any sound physical basis for the idea that they can influence the earth's weather. The most elaborate attempt of this kind that has thus far been made is that of Veeder, which was recently described in these pages.[2] His results, interesting as they are, cannot be accepted as conclusive. When he wrote some twenty-five years ago, neither the science of physics nor our knowledge of the problems

[2] Ellsworth Huntington: The Geographical Work of Dr. M. A. Veeder, *Geogr. Rev.*, Vol. 3, 1917, pp. 188-211 and 303-316.

mentioned under the two preceding headings was sufficient to permit of final conclusions.

Finally, when the supposed physical cause has at length been determined, it will be necessary to measure its occurrence in the sun most minutely and accurately—a thing which presumably has not yet been done. Only when such measurements are available can we compare them with the weather and apply the final tests which will solve the present controversy.

## The Latest Contribution to the Settlement of the Problem

### Material and Method of the Monograph

Having thus surveyed the general outlines of the greatest meteorological problem of the present day, let us review the latest important contribution to it. Professor Helland-Hansen and Dr. Nansen, as we have seen, belong to the radical group. This, however, is not from any *a priori* theory, but because studies of the temperature of the Atlantic Ocean seem to them to leave no other alternative. Their monograph is one of the most careful meteorological studies ever made. It contains among other things a comprehensive and illuminating review of all the chief contributions to the subject of the sun's relationship to the weather. With this is a full bibliography which is sure to be of great value to the student. They also give tables relating to the temperature, barometric pressure, and wind of many parts of the Atlantic Ocean as well as of some other regions, such as Scandinavia and the United States.

The authors begin with an investigation of the distribution of temperature in the surface waters of the North Atlantic Ocean for the years 1898-1910. On account of the vast amount of labor involved, and also because this season gives the most accurate picture of the main changes from year to year, they limit themselves to three 10-day periods between February 3 and March 4, and three similar periods from March 15 to April 13. Data were collected from all the available ships' logs along the route from New York to the English Channel. Other data were used for the region surrounded by Norway, Iceland, and Scotland, and thence westward and southwestward, also for the oceanic region between Spain and New York and for areas in the equatorial Atlantic. In addition to this a great number of records from all parts of the world were drawn upon. In fact, one of the most impressive features of this monograph is its thoroughness.

### Ocean Temperatures and Currents

The first question to be answered is whether there is any evidence that the temperature of the central parts of the North Atlantic varies in harmony with the temperature and rate of flow of the Gulf Stream and the Labrador Current. Surprising as it may seem our Norwegian authors

can find no clear evidence of this. That the Gulf Stream and the Labrador Current must have an effect upon the temperature of the Atlantic they by no means deny. The ordinary idea as to the effect of the Gulf Stream, for example, assumes that when unusually high temperature is found in a given area, it should gradually move eastward. The rate of movement has been supposed to be such that it takes a year or more for a given condition to pass from Florida to the neighborhood of the English Channel. Hence during the 60 days from the middle of the first to the middle of the last of the 10-day periods with which our authors work, the center of an unusually warm area, for example, should advance from a sixth to a tenth of the distance from Florida to the coast of France. Not once during the thirteen years covered by the investigation is this expectation realized. On the contrary, there is a pronounced tendency toward somewhat sudden and irregular changes. An excess of temperature is soon followed by a deficiency. This in turn may in a few weeks be followed by another excess. Moreover, the changes do not proceed gradually from west to east, but show a tendency to occur simultaneously over areas extending a thousand or more miles from east to west. As a result of this tendency we do not find a gradual change from above normal to below normal, or the reverse, as we pass from west to east across the ocean. On the contrary, the whole Atlantic, aside from the parts near the two continents, generally shows the same kind of departure. That is, at a given time all the central parts of the ocean are likely to be warmer or colder than normal, while the two borders vary in the opposite direction.

Having completed their study of the region between Europe and New York, Helland-Hansen and Nansen turn their attention to other parts of the world. They find, for example, that when the temperature is especially low along the route from New York to England, as occurred in 1904, the same condition prevails over a large part of the North Atlantic as well as over vast areas in other parts of the world. Moreover, so far as there is a progressive movement of warm or cold centers, it does not appear to coincide with the direction of the currents. For instance, in the eastern Atlantic changes in the surface temperature seem to progress from the Azores northeastward and thus across the currents.

## Temperatures and Winds

Having found that short-period changes of temperature do not occur in accordance with what would be expected on the basis of ocean currents, the authors next investigate the winds. They find that over the North Atlantic the temperature of the water varies closely in harmony with the barometric pressure, that is with the strength of the winds. Off the coast of Norway, where the temperatures of the water and of the land have been supposed to be closely dependent on the Gulf Stream, a careful investigation shows that this is not the case. Of course in the long run a change in

the Gulf Stream would be important, but, so far as the short changes from season to season are concerned, it is the wind that counts. The temperature of the coastal waters and of the air over the land varies in harmony with the wind. At Stockholm the changes in temperature are almost identical with those on the western coast of Norway. Moreover, as a rule the changes at Stockholm come a trifle earlier than on the west coast. Therefore we seem forced to the conclusion that "the immediate general cause of short changes . . . is undoubtedly to be sought in the changes in the atmospheric pressure."

### Widely Separated Regions

This conclusion leads our authors to still further investigation. In accordance with the method of 12-monthly overlapping averages so profitably employed by Arctowski they compare their curves for North Atlantic regions with those for other parts of the world. The relationships are extraordinary. In the first place a great body of data shows that places as remote as the North Atlantic in latitudes 40°–50°, the equatorial Atlantic, Batavia in Java, Arequipa in Peru, and Bulawayo in South Africa are subject to almost the same synchronous series of small changes of temperature. In other places such as Honolulu the curve of temperature is almost the reverse of the Arequipa type. Between the two types there is every gradation. Moreover, a curve may suddenly change from one to the other. Such was the case on a wide scale about 1896. At that time a marked change of type occurred not only in temperature curves but in those representing atmospheric pressure and wind. According to Lockyer, a corresponding change in the sun, as indicated by the spectroscope, occurred at the same time.

### Significance of these Data

The significance of these many curves from all parts of the world lies in the fact that their uniform periodicity points to some great cause outside the earth. That cause can only be the sun. It can scarcely, however, be the changes in the amount of *heat* emitted by the sun. The reason for this belief is as follows: Changes in solar temperature must produce their greatest effect in those parts of the earth where the sun at any given season shines most nearly vertically or with the least hindrance from clouds. From such places the heat would gradually spread outward, especially in the direction of the prevailing winds or currents. Under such circumstances places farther and farther removed from the regions of greatest heating would show less and less effect, and the delay would be greater and greater as we get farther away from the starting point. In some cases this is what happens, and we may well conclude that under such circumstances we are dealing with the direct effect of changes in the sun's thermal radiation. Far more often, however, we find simultaneous changes in remote places with wholly different climatic characteristics. Thus at

the equator about 30° west of Greenwich the ocean off the west coast of Africa undergoes changes of temperature almost identical with those about 45° farther north and about 45° west of Greenwich, that is off Newfoundland. Half way between these two places, however, the changes of temperature are almost exactly the reverse. It is noteworthy that at the equator and in latitude 45° N. in the Atlantic Ocean *low* pressure prevails permanently, while in the intervening region there is an area of permanent *high* pressure.

Similar instances might be multiplied. They seem to show that Hildebrandsson is right in his idea of centers of action. Apparently solar activity produces two kinds of effects, one in areas of high pressure and the other in areas of low pressure. Therefore the curves showing the changes of temperature from month to month in the two regions are reversed. In intermediate regions there are likely to be transition types. In places near the limits of the various centers of barometric action, predominantly high-pressure conditions may prevail at one time and low-pressure conditions at another. Thus mixed types of temperature curves may be produced. In this way what seems at first to be a perfect chaos, full of interminable contradictions, falls into an orderly and systematic sequence. It falls into such a sequence, however, *only if we admit that the primary effect of solar changes is to cause variations in atmospheric pressure.* If the sun's variations are primarily thermal, the chaos still remains chaos.

## Criticisms of the Authors' Conclusions

This general conclusion of Helland-Hansen and Nansen seems to be wholly in accord with the evidence. In certain minor respects, however, their conclusions are open to question. For instance, they conclude that at times of sunspot maxima the extremes of temperature from day to day and season to season are no greater than at other times. This is directly opposed to the conclusions of Hann, Liznar, MacDowall, and Easton, all of whom are quoted by our authors. It seems also to be opposed to the evidence presented in the book under discussion by the authors themselves. Their curves of the difference between the warmest and the coldest months in various parts of the United States show a considerable resemblance to the sunspot curve, especially when all sections of the country are combined. They show a still greater resemblance to the curve of solar protuberances.

Another point which seems open to possible criticism is the effort of the authors to find exact periodicities. Thus they speak not only of periods of 14 and 27 days due to the sun's rotation, but of periods of 4, 8, and 12 months, periods of 2, 2.7, and 3.5 to 4 years, periods of 5 to 6, 11, and 33 to 35 years, and many other periods which slip from the memory. It may be that all these periods are real. It is certainly most fascinating to work with them. Almost everyone who studies sunspots or the weather is

lured on and on by the way in which the same phenomena repeat themselves in cycle after cycle. Thus far the net result of studies of this problem seems to be that we have not discovered a single period whose duration and character are such as to make it of practical value. We talk about sunspot periods of 11 years, but they vary from 7 or 8 to 14 or 15 years, and no one can do more than guess as to the length of the next one. The fact seems to be that while the changes in the atmospheres of the earth and the sun are cyclic they are not periodic. That is, the same phenomena keep recurring in cycles of every conceivable magnitude, but they do not recur after the lapse of any definite period. Every one of the apparent periods prevails for a short time—that is for a few cycles or perhaps a score—and then disappears.

## What Is the Real Character of the Sun's Activity?

The consideration of cycles leads to the part of the book which the critic is sure to seize upon. Helland-Hansen and Nansen fail to show as close agreement between solar and terrestrial changes as between terrestrial changes in widely separated parts of the world. Only where the temperature of large numbers of stations is compared with the area of sunspots according to Köppen's method do we find an unmistakable and uniform relationship, extending over a long period. The promptitude with which similar temperature changes appear at short intervals in corresponding pressure areas in remote and unconnected regions is enough to prove that we are dealing with the results of solar activity. Nevertheless the apparent relationship between sunspots and the terrestrial temperature or pressure at individual stations keeps breaking down. The same is true when curves for solar prominences or for variations in magnetic intensity are substituted for sunspots. Each of these types of curves shows certain marked resemblances to the meteorological curves, but none shows the resemblances through long periods. The curve for the solar constant is equally unsatisfactory. In none of these cases, however, is there cause for surprise, as our authors well show. The fact is that although the relation between the sun and the earth seems proved, we do not yet know with what kind of solar activity we are dealing. The active agency is apparently not sunspots themselves, it is not the sun's magnetic action, it is not solar prominences, nor is it the solar constant. Each of these doubtless has some effect. Each is probably closely related to the force for which we are searching. Possibly all these solar phenomena are in themselves merely the effects of some greater, deeper cause, which also acts upon the earth's atmosphere. The authors have done the first part of their work so well that it is to be hoped that they will now take up this next step in the great problem of the relation of the sun to the weather.